DEVELOPMENT OF IMPROVED
GALLIUM ARSENIDE SOLAR CELLS

Second Quarterly Progress Report

Period Covered

1 October through 31 December 1964

Prepared for:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Goddard Space Flight Center
Greenbelt, Maryland

Contract NAS5-9006

Prepared by

RADIO CORPORATION OF AMERICA
Special Electronic Components Division
Direct Energy Conversion Department
Mountaintop, Pennsylvania

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SUMMARY

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This report describes work performed on gallium arsenide
solar cells from 1 October 1964 through 31 December 1964.
Changes in the fabrication procedure are noted as well as
results of electrical measurements and investigations made
on contacting mechanisms.

The first two phases of the three phase program have been
completed. The completed phases consist of obtaining 9%-
11% tungsten efficiency cells having low series resistance,
and high bonding strength contacts. The investigation into
soldering techniques and mechanisms (Phase III) has been
started.

Sn-Ag "N" and Ti-Ag "P" has been chosen as the contacting
mechanism. This combination provides cells with series
resistances in the area of 0.5 ohms. The peel strength is
quite good.

Data are presented on cells that have been life tested at
200°C and 250°C.

AUTHOR

DEVELOPMENT OF IMPROVED
GALLIUM ARSENIDE SOLAR CELLS

Second Quarterly Progress Report
Contract NAS5-9006

I. INTRODUCTION

A. Scope and Purpose

The objectives of this contract are the development of a gallium
arsenide solar cell having a low series resistance contact with
high bonding strength, the improvement of high temperature
reliability, and the accumulation of data relating junction char-
acteristics to electrical results.

The overall general purpose of the program is to fabricate gallium
arsenide solar cells which would have a possible application in
high temperature space missions where silicon solar cells would
no longer be useful.

B. Phases of Work

The work being done under this contract is divided into three phases.
Phase I consists of getting the process to the point where 9% to 11%
tungsten efficiencies can be made routinely. Phase II consists of
developing a contacting mechanism having low resistance and high
bonding strength. Phase III consists of developing a soldering
mechanism which is reliable at high temperatures.

C. Status of Process and Experiments

Phase I and II have been completed and Phase III has been started.

There are normally 50 wafers per week (10 per day) started through
processing with approximately 70% of these reaching final testing.
The remaining 30% are scrapped during processing for breakage,
excessive chips, etc. These problems are basically mechanical and
could be minimized with better fixtures and handling methods. The
electrical distribution is centered in the lower 9% range with numerous
10% and a few 11% cells having been obtained.

A contacting mechanism consisting of Sn-Ag "N" and Ti-Ag "P"
evaporated films has reduced the series resistance from the 2 to 3
ohms obtained when Ni-Ag or Ti-Ag was used for "N" contacts to
less than 0.5 ohms in most cases. In fabricating

this mechanism for the "N" contact the Sn is evaporated followed by an evaporated Ag layer. The "P" contact is essentially the same as that used on silicon solar cells, the Ti is evaporated followed by a Ti-Ag blend followed by an Ag layer.

It is planned to freeze the process at its present status in order to devote the major portion of the remaining work towards improving soldering techniques and achieving a better understanding of high temperature life results. There are still a few minor investigations remaining, however, no major changes are planned.

II. DISCUSSION

A. Crystal Growing

Most of the material received during the months of November and December contained lineage. This is a crystal defect caused by the melt wetting the side of the boat during the growing of the crystal. At first it appeared that good solar cells could not be made with crystals having this defect, however, after further evaluation it was found that fairly good cells could be made depending upon the degree of severity of the lineage. Where the amount of lineage exceeds a given point the shunt resistance decreases drastically causing the knee of the voltage vs. current characteristic to "slump" away from its normal relative squareness. Work is being done to minimize the causes of the defect during the growing operation and to determine the degree of the defect which can be tolerated. It is felt that elimination of the defect will increase the efficiency and reproducibility of the device.

The technique used in growing the crystals tends to produce non-homogeneous impurity distributions in the crystals. By recording data on a wafer from each end of the crystal, it has been observed that the distribution in doping concentration may vary by as much as an order of magnitude and the resistivity as much as a factor of 3. Because of this variation it is difficult to correlate the resistivity with the electrical characteristics. Using the method explained in Measurements (II-B-6) a relative value of resistivity is obtained for each cell. No correlation has been observed between bulk resistivity and efficiency.

B. Experiments

1. Contacts

Normally the wafers are hydrogen fired just prior to contact evaporation (see Appendix I of First Quarterly Progress Report) to remove the oxide intentionally formed before diffusion. The

time between firing and evaporation is kept as short as possible ($\lesssim$ 5 min.) in order to minimize oxide build-up. Two groups of cells were allowed to remain in room atmosphere for 1-1/2 and 3 hours respectively, before the contacts were evaporated. As compared to the normal, there was no degradation in contact strength of either group. It is thus concluded that oxide build-up before evaporation is an insignificant variable at this point in the development of the device.

The Sn-Ag "N" contact mentioned previously (Section I-C) was settled upon after Sn-Ni-Ag (used on GaAs lasers being fabricated at RCA Laboratories, Princeton, N. J.) was tried several times. After investigation it was found that the Ni was unnecessary to the mechanism. Although the melting point of the Sn-Ag eutectic is only 221°C the addition of the In-Ag-Pb solder used raises the melting point beyond the 250°C requirement set for the device. This will be discussed in more detail in the section on soldering.

2.   Shallow Junctions

As mentioned in the First Quarterly Progress Report, it appears that in order to achieve major improvement in increasing the conversion efficiency of GaAs solar cells, the device must be fabricated utilizing a diffused junction depth of less than 0.5 microns. As has been reported previously, a junction on the order of 2 microns is necessary to prevent the presently used contact mechanism from penetrating and shorting the junction. Following the application of the contact, the surface not covered by contact material is etched in order to remove the surface to approximately 0.5 microns from the junction.

Since GaAs is a front wall solar cell it is necessary to have the surface extremely close to the junction in order to optimize the collection efficiency. This presently necessary compromise of diffusing deep followed by etching is a twofold handicap to the conversion efficiency; (a) the surface concentration is reduced causing an increase in series resistance and a degradation of the VI characteristic, and (b) the diffused impurity profile is altered causing a decrease in junction collection efficiency.

Several diffusion experiments have been conducted to illustrate the above mentioned second handicap. Diffusions made at twice the normal time (at the normal temperature) produced a maximum short circuit current (after etching the surface) of 15 ma. Diffusions made at the normal time and 30% less than the normal time (at temperatures 25°C above the normal temperature) produced a maximum short circuit current of 19 ma. Normal diffusions produce a maximum short circuit current of approximately 25 ma (see

Table I). Following the above investigations it was concluded that the short circuit current (thus collection efficiency) is very sensitive to changes in the shape of the impurity profile of the diffused region.

TABLE I

Diffusion Parameters Vs. Short Circuit Current

Diffusion Temperature	Diffusion Time	Optimized Short Circuit Current
N	2N	15 ma
N + 25°C	N; N-30%	19 ma
N	N	25 ma

N = normal processing time or temperature

Extremely short diffusions were made at the normal temperature in order to investigate the spectral response (once again related to collection efficiency) of very shallow ($\sim$0.5 micron) junctions. The electrical characteristics of these cells were poor; however, they exhibited a decided increase in response in the short wavelength region over cells that were normally processed.

Upon completion of the above investigations, it was concluded that the scope and length of the program did not permit the amount of work to be done which would be necessary to solve the problems involved in making shallow junction cells. It should be noted that it is strongly recommended that a complete investigation be made into increasing efficiency by fabrication techniques which include shallow diffused regions.

3. Diffusion

In addition to the above mentioned diffusion studies, there have been other investigations conducted in this area.

A few groups of cells were diffused in which half of the cells

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received the chromic acid treatment and half had not.
There was no significant difference in the electrical
characteristics; however, it must be pointed out that
these cells were fabricated at a time when most cells
exhibited relatively poor characteristics. No signifi-
cant conclusion could be drawn from the tests; therefore,
they will be repeated.

Keeping normal diffusion temperatures, the time has been
shortened to find the minimum junction depth with which
good cells may be made. It appears that 1.5 microns is
the limiting junction depth. It is not known whether the
limiting factor is contact penetration or the non-planarity
of the junction caused by the crystal defects mentioned
earlier.

4.   Soldering

The first attempts at soldering wires to the cells were less
than satisfactory; however, with some minor changes, very
good results were obtained.

First attempts involved Sn-Pb eutectic solder (melting point
$183^{\circ}C$). If the soldering iron was allowed to remain in contact
with the cell for any more than a brief period of time (approx.
3 seconds) there would be up to a 50% degradation in open cir-
cuit voltage. This degradation would occur only when solder
was applied to the positive contact with no observable differ-
ence whether or not a wire was soldered or the positive contact
just tinned. . Soldering the "N" side did not affect the cell per-
formance. By judicious use of the soldering iron, the problem
was reduced but not eliminated.

It seemed obvious that thermal shock was causing the degra-
dation. The cell was placed on a hot plate at a temperature
just below the melting point of the solder. Solder and wires
were applied to the cell while it was on the hot plate to reduce
thermal shock. The results were very encouraging, therefore,
the solder was changed from the lower melting point Sn-Pb to
a In-Ag-Pb (2%-1.5%-96.5%) solder with a melting point of $305^{\circ}C$.
Extremely good results were achieved by keeping the cell at
approximately $260^{\circ}C$ while soldering. Of 20 cells soldered, using
the above method, there was no degradation observed in any of
the cells.

An attempt was made to fabricate a six cell gallium arsenide
module using spare connectors from a silicon solar cell module

program. Since there was no jigging available it was made entirely by hand. The electrical characteristic was quite good. If time and material are available, another module will be fabricated.

The peel strength of the "N" contact has been in excess of 800 grams in all tests made. As mentioned in the section dealing with contacts, there was some question as to the mechanical reliability of the contact at elevated temperatures. A test was made to answer this question. Using the In-Ag-Pb material a wire was soldered to a cell. The cell was then placed on a hot plate and an 800 gram weight used to hold the cell in place. A pulling force estimated to be 300 to 400 grams was applied to the wire in an upwards direction normal to the cell. The hot plate was then turned on and an account was kept of the temperature. When the temperature reached 300°C the test was discontinued with no observable deterioration of the contact strength.

Difficulties have been encountered in testing the peel strength of the "P" contact (bus bar). In almost all cases the cell breaks before any significant amount of force may be applied. In a few cases peeling has been observed with the appearance being not unlike that of peeled silicon solar cells (the separation occurring at the Ti and Ag interface). Work will be done in this area to obtain more meaningful data.

5. Spectral Response Vs. Temperature

Spectral response data were recorded as a function of temperature using a Perkin-Elmer spectrophotometer with a temperature controlled cell holding fixture. Data were taken at cell temperatures of 28°C, 50°C, 100°C, 150°C, 200°C and 250°C. There is a shift in the response toward the long wavelength region as the temperature is increased. Fig. 1 is a graph of the ratio of the normalized spectral response value at various temperatures to the normalized spectral response value at 28°C plotted against wavelength (0.50 microns to 0.825 microns). For example, at 0.50 microns there is 28% less response at 250°C than at 28°C, at 200°C there is 22% less response than at 28°C, etc. It should be mentioned that the results are not as drastic as they may appear in Fig. 1. When the device's normalized spectral response is combined with the solar spectral distribution (Johnson's data), there is very little change in the calculated resultant response of the cell at various temperatures due to the gain in red response compensating the loss in blue response. Unfortunately, a graphical display of this is not possible due to the sensitivity of the measuring equipment.

$$R = \frac{\text{Normalized value @ T (X}^O\text{C)}}{\text{Normalized value @ T (28}^O\text{C)}}$$
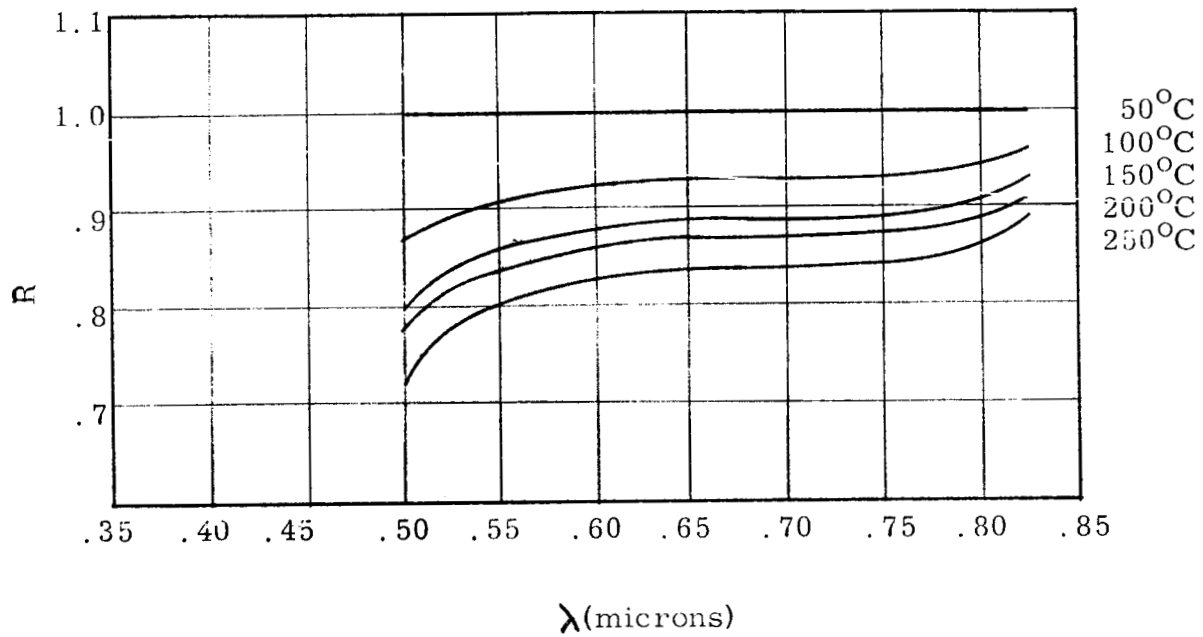
T(X^{O}C) = Temperature in question

Fig. 1.   Temperature Vs. Spectral Response

6. Measurements

(a) **R-C and I_{sc}-V_{oc} Correlation, Ni:Ag Contacts** - From
a group of 40 cells, those representative of three widely
separated performance categories were measured for
series and shunt resistance, and capacitance. The groups,
in terms of short-circuit current and open-circuit voltage
were: (1) low current and low voltage, (2) low current and
high voltage, (3) high current and medium high voltage.
(Note: the combination high current and high voltage did
not occur in this particular group of 40 cells.) The group-
ings of cells and corresponding R-C measurements are
indicated in Table II. It is evident that no definite correla-
tion existed between the R-C parameters and the current-
voltage characteristics.

To further determine what specific basic differences separate
the cells into the particular groups, the spectral response
half-peak band widths were measured. The results, listed
in Table III, show that the high current medium high voltage
cells (group 3) exhibit a 25 to 50% broader spectral response
than the low current cells (groups 1 and 2). This further
verifies that the series and shunt resistances do not, in this
case, uniquely determine the cell performance.

(b) **R-C and Efficiency Correlation Analysis, Sn:Ag Contacts** -

The use of Sn:Ag contacts lowered the 2 to 3 ohm series
resistance measured for Ni:Ag contacts to about 0.1 ohms.
Measurement of the basic resistance and capacitance char-
acteristics of 23 cells from lots 66 through 69 showed the
processing to have improved to a point where the effects of
shunt resistance variations affect the cell efficiencies. The
R-C and I_{sc}, V_{oc}, and η data is given in Table IV. The
basic parameter showing the most definite correlation with
efficiency is the shunt resistance. This is indicated in Fig. 2.
Capacitance values are also given for each resistance-effic-
iency point plotted.

(c) **Resistivity of Base Material** - It was previously established
on Contract NAS5-457, that the period of induced oscillations
in the reverse biased cycle of a sinusoidal driven silicon solar
cell varies inversely with the base resistivity as shown in the
solid line portion of Fig. 3. Assuming that the same empirical
data can be extrapolated as shown and applied to the case of
gallium arsenide solar cells, the resistivity of the processed

TABLE II

Resistance-Capacitance and Current-Voltage Distributions
for Gallium Arsenide Cells Having Nickel:Silver Contacts

				V_{OC} (volts)				
	.760	.780	.800	.820	.840	.860	.880	.900
I_{SC} (ma)	.780	.800	.820	.840	.860	.880	.900	.920

C(uFd)	$R_p (\Omega)$	$R_S (\Omega)$
0.082	420	2.5
0.086	1450	1.8
Group I		

C	R_p	R_S
0.077	460	2.1
0.081	380	2.1
0.089	9000	2.6
0.065	2000	3.1
0.066	230	2.1
0.060	630	1.7
0.055	320	1.7
Group II		

49-50
50-51
51-52
52-53
53-54
54-55
55-56
56-57
57-58
58-59

C	R_p	R_S
0.068	220	2.1
0.078	410	3.0
0.081	140	1.0
Group III		

TABLE III

Spectral Half-Peak Band Width Correlation With
Cell Performance

Category	Spectral Half-Peak Bandwidth, Microns	No. of Cells
1	.22 to .23	2
2	.20 to .24	3
3	.30 to .32	3

TABLE IV

Resistance-Capacitance and Performance Characteristics for Tin:Silver Gallium Arsenide Cells Having Tin:Silver Contact Cells

Cell No.	Lot No.	C uFd	R_s ohms	R_p ohms	I_{sc} ma	V_{oc} volts	η * %
1	66	0.0722	0.40	140	20.4	.900	6.8
2	66	0.0772	0.40	670	18.9	.890	7.0
3	66	0.0718	0.40	320	19.9	.896	8.0
4	66	0.0673	< 0.30	100	22.0	.910	8.8
5	66	0.0724	< 0.30	120	21.0	.890	7.0
6	66	0.0569	< 0.30	850	25.5	.938	10.5
1	67	0.0483	< 0.30	370	20.7	.850	7.5
2	67	0.0517	< 0.30	680	22.5	.880	8.4
3	67	0.0550	< 0.30	240	22.5	.820	6.8
4	67	0.0522	< 0.30	4700	23.0	.900	9.0
5	67	0.0529	< 0.30	500	23.9	.890	9.0
6	67	0.0491	0.40	200	19.9	.804	< 6.5
1	68	0.0571	0.40	1600	24.0	.894	9.0
2	68	0.0570	< 0.30	380	23.4	.880	8.5
3	68	0.0544	< 0.30	1100	23.9	.900	9.4
4	68	0.0566	< 0.30	150	23.0	.884	7.5
5	68	0.0570	< 0.30	400	22.5	.872	8.0
1	69	0.0532	0.40	4200	23.8	.880	9.0
2	69	0.0511	< 0.30	900	22.8	.868	8.5
3	69	0.0500	< 0.30	800	24.6	.910	9.5
4	69	0.0590	< 0.30	4000	21.2	.890	8.3
5	69	0.0550	< 0.30	900	24.0	.886	9.5
6	69	0.0522	0.40	8200	21.7	.884	8.5

C   = junction capacitance at V = O
R_s = series resistance
R_p = shunt resistance
I_{sc} = short circuit current
V_{oc} = open circuit voltage
η = efficiency

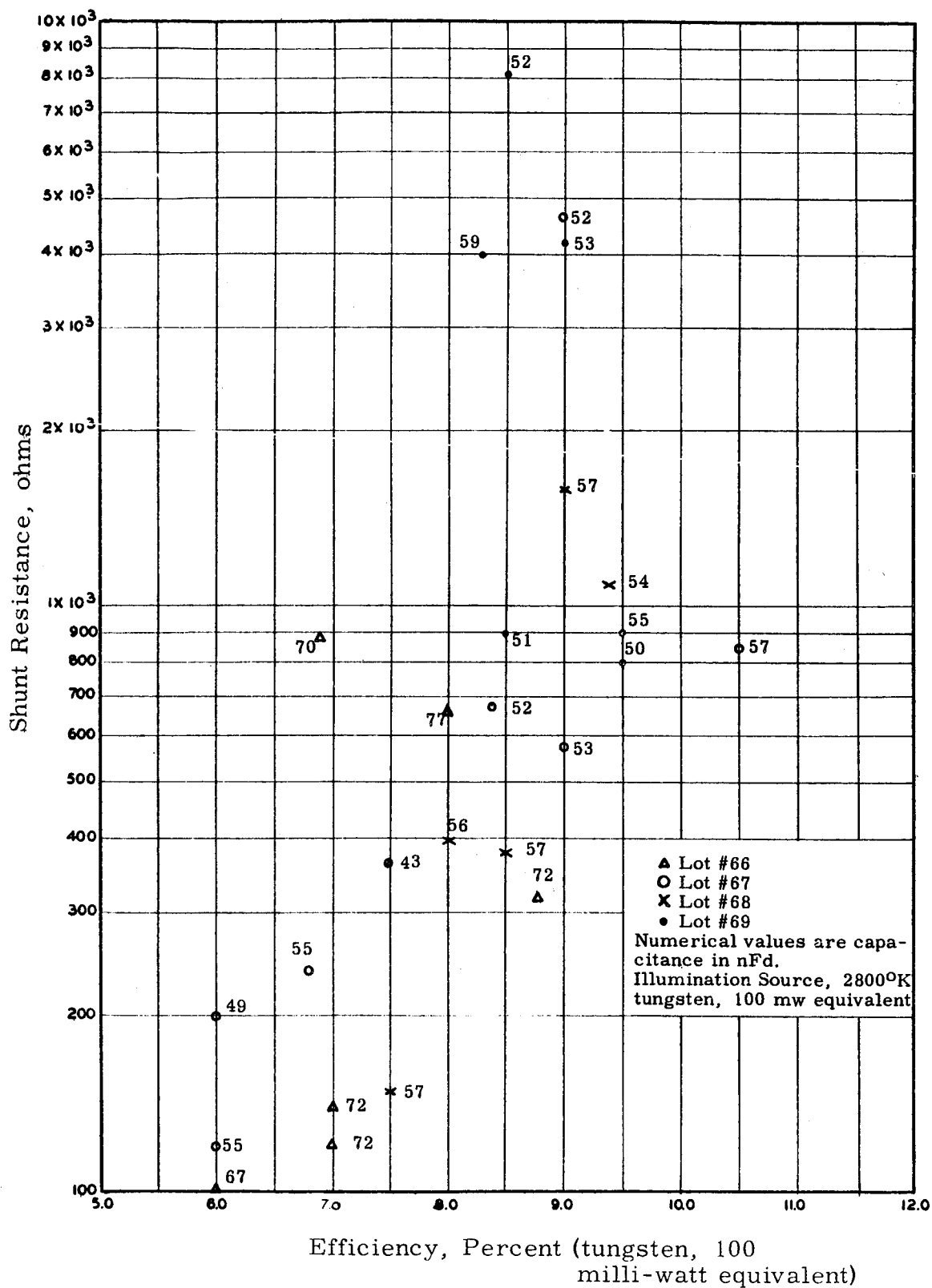*efficiency under 2800°C tungsten source, 100 milliwatt equivalent

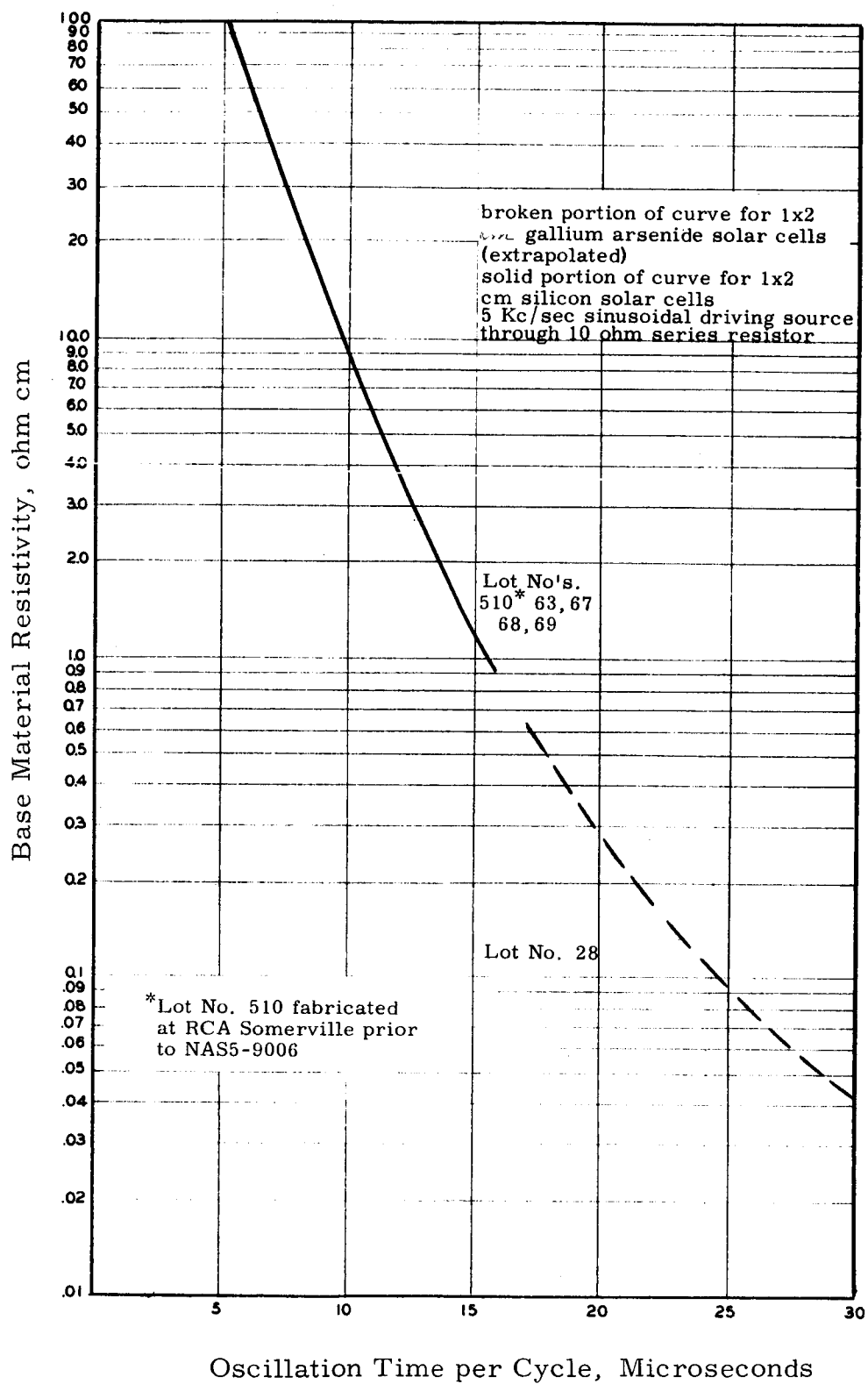Fig. 2. Cell Efficiency Correlation with Shunt Resistance

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Fig. 3. Oscillation Period of Reverse Bias Transient
Versus Base Resistivity

gallium arsenide can be estimated and compared to data on the original crystal. The extrapolated portion of Fig. 3 covers a greater range than the 0.02 to 0.1 ohm cm reported for the starting material. The empirical data suggests the range to extend from 0.04 to 0.5 ohm cm. The discrepancy is not excessive. Comparison of the cell efficiencies for the various lots processed has not shown any significant correlation with the base resistivity as noted from the listing given in Table V.

C. High Temperature Life Testing

High temperature storage tests were performed at temperatures which presently define the upper operating limit of gallium arsenide solar cells. Temperatures of 200°C and 250°C were chosen for initial tests. One group was electrically tested, at intervals, up to 950 hours. A second group has been started. The data recorded on the second group includes series and shunt resistance, junction capacitance, spectral response and current vs. voltage curves.

The first group, fabricated with Ti-Ag contacts on both sides of the cell, was tested after 0, 25, 134, 350 and 950 hours of storage. Tables VI and VII give the results of the 200°C test and 250°C tests respectively. Comparison of the parameters in both groups show approximately the same magnitude of change (except cell 18-4 in the 250°C group) as illustrated by the percent change. If the cause of the changes was thermally sensitive it would be expected that the cells stored at 250°C would degrade more than those stored at 200°C. It may be that the size of the sample is masking any differences that may exist. No explanation can be given at this time for the catastrophic degradation of cell 18-4.

The second group, fabricated with Sn-Ag back and Ti-Ag front contacts, was tested after 0 and 137 hours of storage. The cells were then replaced in storage for further evaluation. Tables VIII and VIIII give the results of the 200°C and 250°C test respectively. The average percent change for the 250°C test shows slightly higher degradation than the 200°C test, however, all data is in reasonable agreement with the results of the first group when measured at 139 hours.

The series and shunt resistance and junction capacitance data taken at 0 and 137 hours are presented in Table X. It was concluded that the cause of degradation was not due to a physical change in the junction or to a failure in the contact structure since the junction

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TABLE V

Measured Oscillation Period of Reverse Bias Transient and Efficiencies of Gallium Arsenide Solar Cells

Lot	Oscillation Period Max. usec	Min. usec	Number of Cells Sampled	η Efficiency Max. Percent	Min.
510*	22	18	10	10.0	6.1
8	26	-	1	7.3	-
11	25	-	1	9.2	-
14	26	-	1	9.6	-
16	26	25	3	9.1	7.4
17	30	27	4	9.2	7.7
18	28	26	6	9.0	7.6
19	27	26	6	10.1	8.9
20	31	28	2	8.7	8.0
21	28	-	2	8.9	8.7
24	28	27	2	8.8	7.7
28	30	24	5	11.1	9.0
29	25	24	5	9.9	8.2
66	24	22	7	10.5	6.5
67	21	19	6	9.0	6.5
68	21	19	5	10.5	6.5
69	20	18	7	9.5	8.3

*Lot 510, fabricated at RCA Somerville prior to NAS5-9006.

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TABLE VI

Parameter Change at 200°C Storage Temp. Ti-Ag Front and Back Contacts

	Cell # 17-8	% Change	Cell # 19-6	% Change	Cell # 29-5	% Change	Avg. % Change
I_{sco}	27.2		26.0		25.7		
25	26.7	1.8	23.8	8.5	25.2	1.9	4.1
139	26.2	3.7	23.5	9.6	24.8	3.6	5.6
350	26.2	3.7	23.5	9.6	cell broken		6.6
950	26.0	8.1	23.3	10.4			9.2
V_{oco}	.870		.756		.890		
25	.860	1.2	.732	3.2	.890	0	2.2
139	.850	2.3	.736	2.6	.876	1.6	2.2
350	.850	2.3	.734	2.9	broken		2.6
950	.857	1.5	.756	0			.8
I_{mpo}	15.5		8.8		16.2		
25	15.2	1.9	7.6	13.6	16.1	.6	5.4
139	14.8	4.5	7.4	15.9	15.4	4.9	8.4
350	14.7	5.2	7.4	15.9	broken		10.6
950	14.8	4.5	7.5	14.8			9.7

TABLE VII

Parameter Change at 250° Storage Temp. Ti-Ag Front and Back Contacts

	Cell # 18-3	% Change	Cell # 18-4	% Change	Cell # 29-4	% Change	Cell # 16-8	% Change	Avg. % Change
I_{sco}	25.3		25.0		24.5		26.6		
25	25.1	.8	24.7	1.2	23.8	2.9	25.7	3.4	2.1
139	24.7	2.8	23.5	6.0	23.7	5.3	25.5	4.1	4.6
350	24.7	2.8	23.2	7.2	23.8	2.9	25.3	4.9	4.5
950	24.5	3.2	23.0	8.0	23.7	5.3	25.0	6.0	5.6
V_{oco}	.852		.810		.836		.868		
25	.852	0	.700	13.6	.824	1.4	.856	1.4	.7
139	.840	1.4	.400	50.6	.820	1.9	.820	5.5	2.2
350	.840	1.4	.350	56.8	.816	2.4	.808	6.9	2.7
950	.840	1.4	.340	58.0	.830	1.9	.808	6.9	2.6
I_{mpo}	16.7		12.8		14.1		12.3		
25	14.1	15.6	7.0	45.3	12.6	10.6	11.7	4.9	7.8
139	14.1	15.6	2.4	81.3	12.4	12.1	10.6	13.8	10.4
350	13.9	16.8	2.1	83.6	12.2	13.5	10.0	18.7	12.3
950	14.3	14.4	2.1	83.6	12.4	12.1	10.2	17.1	10.9

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TABLE VIII

Parameter Change at 200°C Storage Temp. Ti-Ag Front and Sn-Ag Back Contacts

	Cell # 66-2	% Change	Cell # 67-4	% Change	Cell # 67-5	% Change	Avg. % Change
I_{sco}	19.8		19.6		22.9		
137 hrs.	19.3	2.5	18.8	4.1	21.7	5.24	3.9
V_{oco}	.890		.815		.850		
137 hrs.	.860	3.4	.797	2.2	.830	2.4	2.7
I_{mpo}	11.6		10.0		12.8		
137 hrs.	10.4	10.3	9.1	9.0	11.6	9.4	9.6

TABLE VIIII

Parameter Change at 250°C Storage Temp. Ti-Ag Front and Sn-Ag Back Contacts

	Cell # 66-?	% Change	Cell # 66-7	% Change	Cell # 67-6	% Change	Cell # 67-8	% Change	Avg. % Change
I_{sco}	21.8		20.8		19.2		20.3		
137 hrs.	21.2	2.8	20.3	2.4	17.8	7.3	19.2	5.4	4.5
V_{oco}	.915		.890		.890		.800		
137 hrs.	.875	4.4	.860	3.4	.860	3.4	.780	2.5	3.4
I_{mpo}	15.2		12.0		16.3		10.5		
137 hrs.	13.3	12.5	11.0	8.3	15.4	5.5	8.7	17.0	10.8

capacitance and series resistance showed no change. Several
of the test cells showed a degradation in the knee of the current
vs. voltage curves. As can be seen in Table X, there is a
decrease in the shunt resistance of many of the cells. This
could be the reason for the degradation of the curves. More
work is necessary to determine the cause for the decrease in
resistance.

The relative spectral response curves taken at 0 and 137 hours
show a decrease of response in the blue region. Fig. 4 is a
typical example. The percentage loss in area under the curve
was determined by planimeter measurements and is tabulated in
Table XI. There is good correlation between the percentage of
the area lost and percentage of the short circuit lost. More
data are necessary to make a firm conclusion, however in com-
paring the I-V curves and spectral response curves it appears as
though the cells are being "masked" and/or the collection efficiency
is decreasing. Possible causes could be an interaction between the
SiO and GaAs or a change in the GaAs surface causing surface
recombination velocity to increase or a decrease in lifetime.
Attempts will be made to determine the exact cause.

III. CONCLUSIONS AND RECOMMENDATIONS

Using a Sn-Ag "N" or back contact and a Ti-Ag "P" or front contact
the series resistance has been reduced to approximately 0.5 ohms.
This has allowed a correlation to be made between the shunt resistance
and the efficiency of the cell. Prior to the use of the Sn-Ag "N" contact
it was impossible to find correlation between any of the junction char-
acteristics. The peel strength is quite good when In-Ag-Pb solder is
used in conjunction with this contact.

All of the data recorded to date suggests that efficiency can be improved
if techniques can be developed to fabricate cells utilizing a shallow diffused
junction of less than 0.5 mircons. The problems related to developing a
fabrication technique are too complex to solve in the remaining time of
this contract. It is strongly recommended that a complete investigation
be carried out in this area.

By reducing thermal shock to the device during soldering, electrical
degradation has been minimized and to a large extent eliminated. Further
work will be done to lessen the handling difficulties associated with the
soldering operation.

Although the spectral response in the short wavelength region decreases with
increasing temperature, an increase in longer wavelength response offsets

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TABLE X

Parameter Change of Cells Having Sn-Ag Back and Ti-Ag Front Contacts

Cell #	Before Storage			After 137 Hours		
	R_s Ω	R_p Ω	C mmf	R_s Ω	R_p Ω	C mmf
66-2	.4	90	.070	.4	80	.070
66-4	.4	670	.077	.2	700	.078
*66-5	.5	320	.072	.4	310	.072
* 66-7	.4	120	.072	.2	90	.072
67-4	.4	120	.055	.4	100	.053
67-5	.4	240	.055	.4	170	.055
*67-6	.4	4700	.052	.5	6900	.052
*67-8	.4	200	.049	.3	130	.049

$*250^{\circ}C$ storage
others $200^{\circ}C$ storage
R_s - series resistance
R_p - shunt resistance
C - junction capacitance at V = O

TABLE XI

Percentage of Spectral Response Loss After 137 Hours of Storage

$200^{\circ}C$ Storage

	Cell #		
	66-2	67-4	67-5
Percent area lost after storage	5.3	4.6	4.1

$250^{\circ}C$ Storage

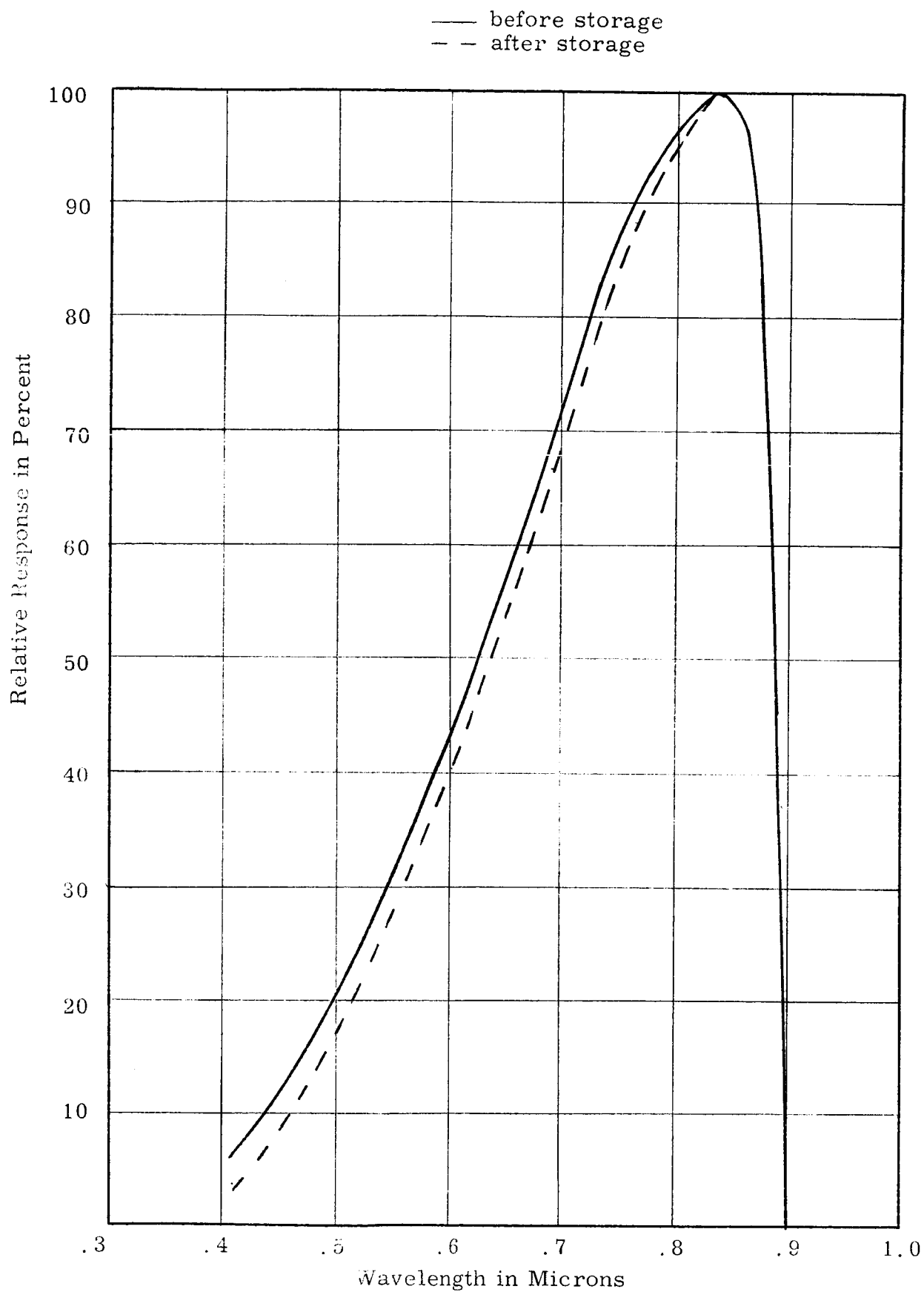|	Cell #			
	66-5	66-7	67-6	67-8
Percent area lost after storage	4.6	6.4	5.1	4.5

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Fig. 4. Spectral Response Before and After 137 Hours
of Storage at 200°C

these losses. The resultant calculated response remains unchanged between temperatures of 28°C and 250°C. when the response of the cell is combined with the solar distribution. In order to investigate this further, sunlight measurements will be taken (weather permitting) at elevated temperatures.

IV. PROGRAM FOR NEXT REPORTING PERIOD

1. Investigate lower diffusion temperatures and longer diffusion times.

2. Continue work to improve soldering techniques.

3. Devise methods of getting meaningful data on the peel strength of the front contact.

4. Measure the cells at elevated temperatures under sunlight (weather permitting).

5. Continue life testing cells.

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